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ASYMMETRIC INTERNATIONAL TRADE

by

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Abstract

The present paper analyzes an example of International Trade between two countries in a model of spatial competition "à la Hotelling". The central assumption of the example is that national buyers face a uniform national price while foreigners pay delivered prices on imported goods. An equilibrium price configuration, when it exists, involves different mill prices in the two countries : the smaller the country, the smaller the mill price. Furthermore, for a price equilibrium to exist, countries must be of different size. Finally, international trade always flows from the smaller to the larger country.

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1. INTRODUCTION

Recently, it has been recognized that a significant portion of international trade develops in imperfectly competitive markets. Evidence of the interest in this aspect of international trade theory can be found in numerous papers which have been recently published in this area (see, for instance, Brander and Spencer [1982], Caves [1979], Jacquemin [1982], Krugman [1979], Lancaster [1980], Rieber [1982]; for a survey of the literature, see Dixit [1984]).

In the present paper, we expand in particular on the role of transportation costs on international trade in a regime of imperfect competition. More precisely, we are concerned with the problem of analyzing international trade between two countries in a model of spatial competition. It is generally observed that no price discrimination can be practiced within the national market by a local firm, while different delivered prices are set on the foreign market. A car Fiat is paid by a dealer the same price at Palermo and Torino, while a higher price is paid by a customer of the same car in Paris than Marseille. There are several possible explanations for this asymmetry between national and foreign delivered prices; one is provided by the fact that the citizen of a country do not bear the transportation cost while foreign customers do. National distribution facilities, or legal prohibition of price differences across different national regions, can in turn explane this advantageous treatment provided to the national customers over the foreigners.

Our analysis stems out from this assumption, so that a citizen of a given country places his purchase order to the national firm, irrespective of the distance to that firm, if and only if the home (mill) price is less than the foreign price plus the transportation cost for importing the product. This choice rule for the customer has to be contrasted with the arbitrage prevailing in classical spatial competition models where firms compete within a given country : there consumers buy from the firm which sets the smallest *delivered* price. This difference has important implications in terms of spatial and price competition on the international market. As we shall see in the example treated in the present note it may introduce fundamental asymmetries in trade between countries. First a price equilibrium on the international market can exist only if national firms quote different (mill) prices. Second international trade must necessarily flow from the smaller to the larger country. Third, for an equilibrium to obtain on the international market, it may be necessary that a significant asymmetry exists between the sizes of the two countries.

These assertions are established in this paper for a particular model directly inspired by Hotelling's contribution in the theory of spatial competition

(Hotelling [1929]). More precisely, we assume a linear market representing two adjacent countries. In each country is located a single firm producing an homogeneous good at no cost, and we study the resulting noncooperative price equilibria in the exchange between the two countries. The model is outlined in Section 2, the equilibrium analysis is provided in Section 3, and the results are briefly commented in Section 4.

2. THE MODEL

To represent the two adjacent countries, we choose a model "à la Hotelling" where the population of buyers in countries 1 and 2 is spread uniformly over a line $[0,L]$, where country 1 includes all buyers in $[0,F]$, while country 2 includes all buyers in $]F,L]$. In each country there is a firm producing a homogeneous good : they are located at respective distances a and b from the ends of this line ($a \in [0,F]$, $b \in]F,L]$, $a + b \leqslant L$; $a \geqslant 0$, $b \geqslant 0$; cfr Figure 1).

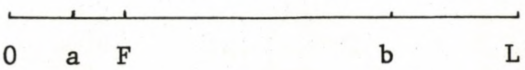

Figure 1

Each buyer purchases exactly a single unit of the commodity, either from his home firms, or by importing it from the firm located in the other country, beyond the border F . We assume that the unit price to be paid by a citizen of a particular country is uniform within the country. On the contrary, if the product is imported, the buyer has to pay the transportation cost from the foreign firm to his home, in addition to the price set by the foreign firm. The transportation cost is linear in distance. Formally, letting t denote a particular customer in country 1, $t \in [0,F]$ (resp. country 2, $t \in]F,L]$) , t will buy from his home firm, if and only if

$$p_1 \leqslant p_2 + c(L-b-t)$$

(resp. $p_2 \leqslant p_1 + c(t-a)$) , where p_1 and p_2 denote the prices set by firm 1 and 2, respectively, and the scalar c denotes the transportation cost per unit of distance. Given (p_1,p_2) the set of customers placing their purchase order at firm 1 is given by

$$\{t \in [0,F] \mid p_1 \leqslant p_2 + c(L-b-t)\} \cup \{t \in]F,L] \mid p_2 > p_1 + c(t-a)\} ;$$

or :

$$\left[0 \ , \ \mathrm{Min}\left\{F \ , \frac{p_2 - p_1 + c(L-b)}{c}\right\}\right] \cup \left]F \ , \ \mathrm{Max}\left\{F \ , \mathrm{Min}\left\{\frac{p_2 - p_1 + ac}{c} \ , \ L\right\}\right\}\right] .$$

Similarly the set of customers placing their purchase order at firm 2 is

$$\left\{t \in \left]F,L\right] \mid p_2 \leqslant p_1 + c(t-a)\right\} \cup \left\{t \in [0,F] \mid p_1 > p_2 + c(L-b-t)\right\} ,$$

or :

$$\left[\mathrm{Max}\left\{F \ , \ \frac{p_2 - p_1 + ac}{c}\right\}, L\right] \cup \left[\mathrm{Min}\left\{F \ , \mathrm{Max}\left\{\frac{p_2 - p_1 + c(L-b)}{c}, 0\right\}, F\right\}\right] .$$

Let us define $\overline{p}_1$ as the solution of the equation

$$F = \frac{p_2 - p_1 + ac}{c} ,$$

i.e. $\overline{p}_1 = p_2 - c(F-a)$: if seller 1 sets a price exceeding $\overline{p}_1$, given p_2 , no customer from country 2 would still import from firm 1. Similarly, define $\overline{\overline{p}}_1$ as the solution of the equation

$$F = \frac{p_2 - p_1 + c(L-b)}{c} ,$$

i.e. $\overline{\overline{p}}_1 = p_2 + c(L-b-F)$: if seller 1 sets a price exceeding $\overline{\overline{p}}_1$, given p_2 , some customers from country 1 are now importing from country 2. Notice that $\overline{p}_1 < \overline{\overline{p}}_1$ when $L-b \neq F$, as it is assumed. Hence in the domain $[\overline{p}_1 , \overline{\overline{p}}_1]$, demand addressed to firm 1 remains totally inelastic to p_1 , and consists of the whole national market, i.e. demand is equal to F . In an analogous way, we can define $\overline{p}_2 = p_1 - c(L-b-F)$ and $\overline{\overline{p}}_2 = p_1 + c(F-a)$, and demand addressed to firm 2 remains equal to $L - F$ in the domain $[\overline{p}_2 , \overline{\overline{p}}_2]$.

We are now in a position to derive the (contingent) demand functions to firm 1 and 2, respectively. We have

$$\begin{aligned} D(p_1,p_2) &= \mathrm{Min}\left\{L \ , \ \frac{p_2 - p_1 + ac}{c}\right\} , && \text{if } 0 \leqslant p_1 < p_2 - c(F-a) ; \\ &= F && \text{, if } p_2 - c(F-a) \leqslant p_1 \leqslant p_2 + c(L-b-F) ; \\ &= \frac{p_2 - p_1 + c(L-b)}{c} && \text{, if } p_2 + c(L-b-F) < p_1 \leqslant p_2 + c(L-b) ; \\ &= 0 && \text{, if } p_2 + c(L-b) < p_1 . \end{aligned}$$

$$D_2(p_1,p_2) = \text{Max}\left\{L\,,\, L - \frac{p_2 - p_1 + c(L-b)}{c}\right\} \quad , \text{ if } \quad 0 \leqslant p_2 < p_1 - c(L-b-F) \;;$$

$$= L - F \quad , \text{ if } \quad p_1 - c(L-b-F) \leqslant p_2 \leqslant p_1 + c(F-a) \;;$$

$$= L - \frac{p_2 - p_1 + ac}{c} \quad , \text{ if } \quad p_1 + c(F-a) < p_2 \leqslant p_1 + ac \;;$$

$$= 0 \quad , \text{ if } \quad p_1 + ac < p_2 \,.$$

Figure 2 describes $D_1(p_1,p_2)$ as a function of p_1 .

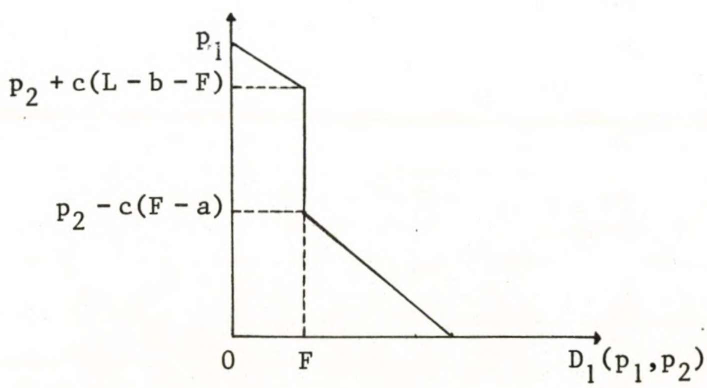

Figure 2

The revenue functions of the firms, corresponding to these contingent demand functions write as $R_1(p_1,p_2) = p_1 \cdot D_1(p_1,p_2)$ and $R_2(p_1,p_2) = p_2 \cdot D_2(p_1,p_2)$, respectively. We notice that both demand and revenue functions are continuous. but neither of them is concave. Figure 3 provides a representation of $R_1(p_1,p_2)$.

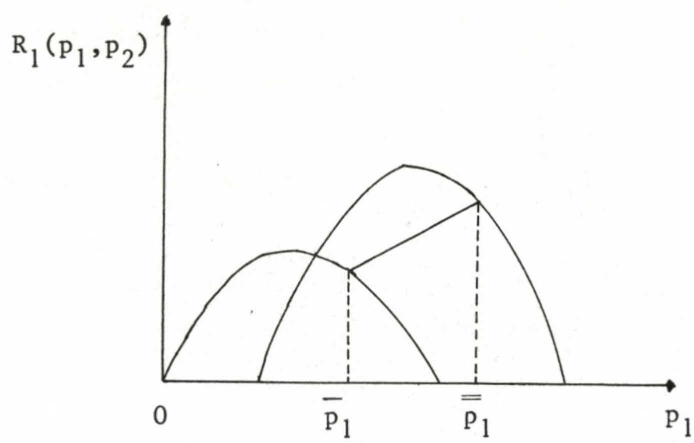

Figure 3

3. THE EQUILIBRIUM ANALYSIS

We are interested in characterizing a noncooperative market outcome on the international market, i.e. a pair of prices (p_1^*, p_2^*) such that no firm can profitably deviate from p_i^*, $i = 1, 2$. To this end, assume that (p_1^*, p_2^*) is a price equilibrium, and define the following domains :

$$D_{11} = \left\{ p_1 \mid p_2^* + c(L-b) \geqslant p_1 > p_2^* + c(L-b-F) \right\}$$

$$D_{12} = \left\{ p_1 \mid p_2^* + c(L-b-F) \geqslant p_1 \geqslant p_2^* - c(F-a) \right\}$$

$$D_{13} = \left\{ p_1 \mid p_2^* - c(F-a) > p_1 \geqslant 0 \right\} .$$

In an analogous manner, define

$$D_{21} = \left\{ p_2 \mid p_1^* + ac \geqslant p_2 > p_1^* + c(F-a) \right\}$$

$$D_{22} = \left\{ p_2 \mid p_1^* + c(F-a) \geqslant p_2 \geqslant p_1^* - c(L-b-F) \right\}$$

$$D_{23} = \left\{ p_2 \mid p_1^* - c(L-b-F) > p_2 \geqslant 0 \right\} .$$

The graphs of the demand functions $D_1(p_1, p_2^*)$ and $D_2(p_1^*, p_2)$, and the corresponding domains of prices are represented on Figure 4.

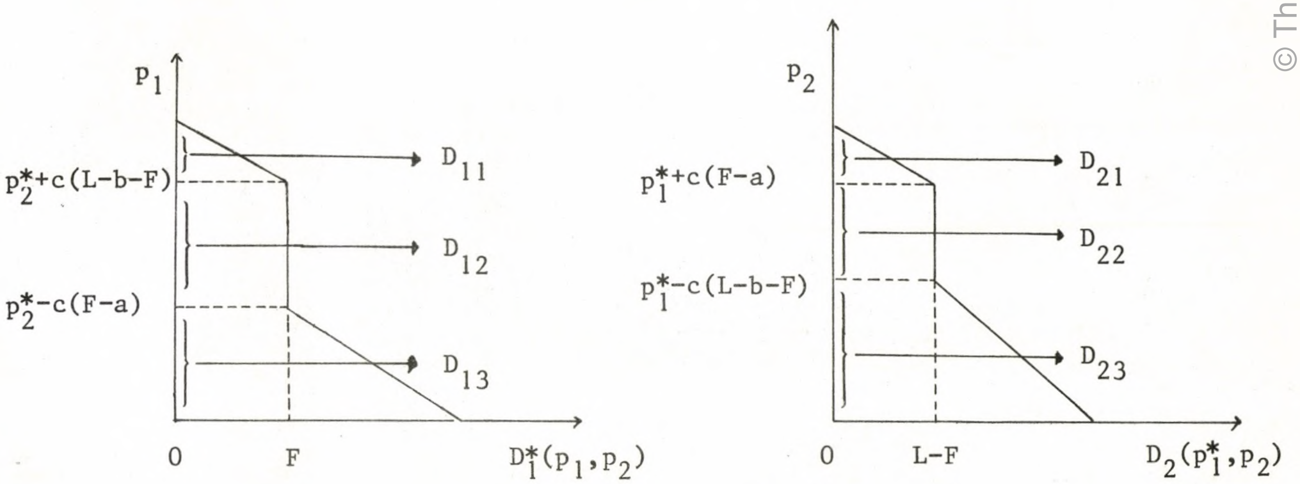

Figure 4

First, we prove

PROPOSITION 1

If a price equilibrium (p_1^*, p_2^*) *exists, it is defined by*

$$p_1^* = \frac{c}{3}(L+a)\ , \quad p_2^* = \frac{c(2L-a)}{3} \quad \textit{(equilibrium of type I),}$$

or by
$$p_1^* = \frac{c}{3}(L+b)\ , \quad p_2^* = \frac{c(2L-b)}{3} \quad \textit{(equilibrium of type II)}\ .$$

Proof : The proof of the proposition proceeds by eliminating various domains of price pairs which are not admissible as price equilibria. First no price equilibrium can obtain with $p_1^* \in D_{12}$ and $p_2^* \in D_{22}$. Indeed, since demand is inelastic to price in the corresponding range for each firm, revenue maximization in D_{12} implies that $p_1^* = p_2^* + c(L-b-F)$, and revenue maximization in D_{21} implies $p_2^* = p_1^* + c(F-a)$; these two implications are clearly impossible together. Similarly, no price equilibrium can occur with $p_1^* \in D_{11}$ and $p_2^* \in D_{22}$ (or the symmetric case : $p_1^* \in D_{12}$, $p_2^* \in D_{21}$) : when $p_2^* \in D_{22}$, it must be equal to $p_1^* + c(F-a)$, so that $p_2^* > p_1^*$, contradicting the fact that $p_1^* \in D_{11}$. Furthermore, an equilibrium (p_1^*, p_2^*) with $p_1^* \in D_{11}$ and $p_2^* \in D_{21}$, or $p_1^* \in D_{13}$ and $p_2^* \in D_{23}$, is also impossible for obvious reasons. We must finally exclude the case where $p_1^* \in D_{13}$ and $p_2^* \in D_{22}$ (or the symmetric case : $p_1^* \in D_{12}$ and $p_2^* \in D_{23}$). In that case, it must be that $p_2^* = p_1^* + c(F-a)$, so that $p_1^* = p_2^* - c(F-a) \notin D_{13}$, a contradiction. Consequently, we are left with the only possibilities : (i) $p_1^* \in D_{13}$ and, simultaneously, $p_2^* \in D_{21}$, and/or (ii) $p_1^* \in D_{11}$ and, simultaneously, $p_2^* \in D_{23}$.

In case (i), since the pair (p_1^*, p_2^*) is assumed to be a price equilibrium, the prices p_1^*, p_2^* must solve simultaneously

$$\max_{p_1 \in D_{13}} \left(\frac{p_2^* - p_1 + ac}{c}\right) \cdot p_1$$

and

$$\max_{p_2 \in D_{21}} \left(L - \frac{p_2 - p_1^* + ac}{c}\right) \cdot p_2\ .$$

Since D_{13} and D_{21} are both semi-open intervals, the pair (p_1^*, p_2^*) can be an equilibrium only if the prices are interior to D_{13} and D_{21}, respectively. Accordingly, first order conditions must be satisfied, which imply that $p_1^* = \frac{c}{3}(L+a)$ and $p_2^* = \frac{c(2L-a)}{3}$ (equilibrium of type I).

In case (ii), the prices p_1^* and p_2^* must solve simultaneously

$$\underset{p_1 \in D_{11}}{\text{Max}} \left(\frac{p_2^* - p_1 + c(L-b)}{c}\right) \cdot p_1$$

and

$$\underset{p_2 \in D_{23}}{\text{Max}} \left(L - \frac{p_2 - p_1^* + c(L-b)}{c}\right) \cdot p_2 \, .$$

Since D_{11} and D_{23} are semi-open intervals, the pair (p_1^*, p_2^*) can be an equilibrium only if the prices are interior to D_{11} and D_{23}, respectively. Accordingly, first order conditions must be satisfied, which imply that $p_1^* = \frac{c}{3}(L+b)$ and $p_2^* = \frac{c(2L-b)}{3}$ (equilibrium of type II).

$\square$

We notice that an equilibrium of type II is simply an equilibrium of type I where a has been replaced by b. In the following, we study equilibria of type I, but everything which is said about these equilibria applies, *mutatis mutandis*, to equilibria of type II.

To obtain a type I-equilibrium, it must be that p_1^* belongs to the interior of D_{13}, and p_2^* to the interior of D_{21}, which in turn implies $p_1^* < p_2^*$. The last inequality can hold only if $a < \frac{L}{2}$. From this we infer immediately that if $F \geqslant \frac{L}{2}$, any location of firm 1 in the interval $[\frac{L}{2}, F]$ is not compatible with the existence of an equilibrium of type I (a similar reasoning applies, *mutatis mutandis*, to equilibria of type II if $F < \frac{L}{2}$). Consequently, we must restrict ourselves to a-values strictly smaller than $\frac{L}{2}$ in the analysis of equilibrium of type I (resp. of b-values strictly smaller than $\frac{L}{2}$ in the analysis of equilibria of type II).

PROPOSITION 2

No equilibrium of type I (resp. type II) exists if country 1 (resp. country 2) is larger, or equal to country 2 (resp. country 1).

Proof : Assume that (p_1^*, p_2^*) is an equilibrium of type I with $F \geqslant \frac{L}{2}$ and $a < \frac{L}{2}$. Then $R_1(p_1^*, p_2^*) = \frac{c(L+a)^2}{9}$. If firm 1 chooses a price $p_1 = p_2^*$, it realizes a revenue $R_1(p_2^*, p_2^*) = F \cdot \frac{c(2L-a)}{3}$. Direct comparison shows that

$$R_1(p_2^*, p_2^*) > R_1(p_1^*, p_2^*) \Leftrightarrow 3F(2L-a) > (L+a)^2 \, .$$

Since a must be strictly smaller than $\frac{L}{2}$, all values of F larger or equal to $\frac{L}{2}$ verify the last inequality. But then the strategy $p_1 = p_2^*$ beats p_1^*

against p_2^* , a contradiction to the fact that (p_1^*, p_2^*) is an equilibrium of type I.

□

Proposition 1 implies that *if an equilibrium exists on the international market, it is never autarkic* : the country setting the smallest price exports to the other. Proposition 2, in turn, says that *there must be an asymmetry in the sizes of the countries for an equilibrium to exist on the international market.* Moreover at equilibrium, it is always the smaller country the one which exports to the larger. A further implication of Proposition 1 is that, since both $D_1(p_1^*, p_2^*) = \frac{L+a}{3}$ and $p_1^* = \frac{c(L+a)}{3}$ are increasing with a , so is $R_1(p_1^*(a), p_2^*(a))$ in the domain of a-values where an equilibrium of type 1 exists; therefore firm 1 will locate as close as possible to the border in this domain. This reflects the fact that firm 1 exporting to country 2, tries to approach its customers located beyond the border[1]. In fact, when a price equilibrium exists on the border F , then firm 1 will find it advantageous to locate on the border. This "attraction property" is interesting to study, to the extent that it is often observed, in countries with an important foreign trade, that industries cluster towards their neighbours markets (good examples are provided by Italy or England). In the following it is our purpose to derive an example where this attraction property is fully realized within our model. In other words, we show that there exist values of F such that if firm 1 locates at F , a price equilibrium of type I exists. To this end, we take the particular case $b = a$, as on Figure 5.

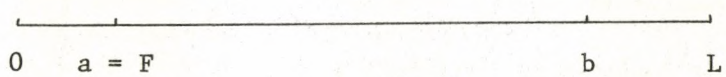

Figure 5

PROPOSITION 3

Let $F = a = b$. *Then the set of* F*-values for which there exists an equilibrium of type I is non-empty.*

Proof : If Lemma 1 (see appendix) is satisfied, then the price $p_1^* = \frac{c(L+a)}{3}$ is a best reply against $p_2^* = \frac{c(2L-a)}{3}$ if, and only if,

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[1] The same incentive does not appear for firm 2, since its profits at an equilibrium of type 1 are independent of b .

$$R_1(p_1^*, p_2^*) \geqslant R_1(p_2^* + c(L-b-F), p_2^*) . \qquad (1)$$

Substituting for b and F , (1) holds iff

$$\frac{c(L+a)^2}{9} \geqslant \frac{ca(5L-7a)}{3}$$

or $L^2 - 3aL - 20\,a^2 \geqslant 0$, or iff

$$a \leqslant \frac{13 - L\sqrt{249}}{-40} \underset{\text{def}}{=} \rho^* \simeq \frac{3L}{40} .$$

For these values of a , the condition of Lemma 1 is satisfied so that, if $a \leqslant \rho^*$, p_1^* is a best reply against p_2^* for firm 1.

To show that p_2^* is a best reply against p_1^* for firm 2, first notice that Lemma 2 is also satisfied for all values of $a \leqslant \rho^*$. Furthermore, we are left with the comparison of $R_2(p_1^*,p_2^*)$ with $R_2(p_1^*, p_1^* + c(F-a)) = R_2(p_1^*,p_1^*)$ since $F = a$. From direct comparison, we get

$$R_2(p_1^*,p_2^*) = \frac{c(2L-a)^2}{9} > \frac{c(L+a)}{3}(L-a) = R_2(p_1^*,p_1^*)$$

if $L > \frac{a}{2}$.

Three conclusions can be drawn from Proposition 3. First, it shows that the "attraction property" can hold : the exporting firm optimizing its location sets up its plant next to the foreign market. Second, in the example considered, a striking asymmetry in size between the two countries is needed for observing an equilibrium of type I when the small country firm locates optimally on the border. Finally, Proposition 3 provides, as a byproduct, an example where a price equilibrium exists on the international market for the model we have considered, giving content to Propositions 1 and 2.

4. SUMMARY AND CONCLUSIONS

We have here described a suggestive example of the manner in which transportation costs for exports, when they are borne by foreign customers, may influence international trade. The central feature of this example are that national buyers face a uniform national price while foreigners pay delivered prices on imported goods.

We have shown how competition between rival firms located in different countries operates when this asymmetric pricing rule is used. In particular, mill prices in both countries must necessarily be different at an equilibrium in the international market, which cannot occur if countries are of the same size. Furthermore, *in equilibrium, when it exists, international trade always flows from the smaller to the larger country, and the exporting country has the lower mill price.* The intuition behind this asymmetry lies in the fact that the firm in the larger country has a sizeable local market, and does not find advantageous to lower its price for attracting foreign customers, while the inverse holds for the firm in the smaller one. Finally, the exporting firm is "attracted" towards the border, approaching thereby its foreign customers, but reinforcing price competition with the firm located in the other country.

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APPENDIX

LEMMA 1 :

Let $p_2^* = \frac{c(2L-a)}{3}$ *and* $a = b = F < \frac{L}{2}$; *then, either* :

$$\forall\ p_1\ ,\ R_1\left(\frac{c}{3}(L+a)\ ,\ p_2^*\right) \geqslant R_1(p_1,p_2^*)\ ,$$

or $$\forall\ p_1\ ,\ R_1(p_2^* + c(L-2a)\ ,\ p_2^*) \geqslant R_1(p_1,p_2^*)\ .$$

Proof : In any case if a price $\tilde{p}_1$ verifies the property :

$$\forall\ p_1\ ,\ R_1(\tilde{p}_1,p_2^*) \geqslant R_1(p_1,p_2^*)\ ,$$

it must be that $\tilde{p}_1$, after substitution for b and F , is solution of either

$$\max_{p_1 \in D_{13}} \left(\frac{p_2^* - p_1 + ac}{c}\right) \cdot p_1\ , \tag{1}$$

or $$\max_{p_1 \in D_{11}} \left(\frac{p_2^* - p_1 + c(L-a)}{c}\right) \cdot p_1\ , \tag{2}$$

or $$\max_{p_1 \in D_{12}} \{ap_1\}\ , \tag{3}$$

where D_{11} , D_{12} and D_{13} are defined as in Proposition 1. First, let us show that if $a < \frac{L}{2}$, as supposed, the solution $\tilde{p}_1$ to problem (3) must lead to a revenue $R_1(\tilde{p}_1,p_2^*)$ which exceeds $R_1(p_1,p_2^*)$ for all p_1 in D_{11} , leaving us with either case (1) or (3). First, it is clear that $\tilde{p}_1$ solution of problem (3), is equal to $p_2^* + c(L-2a)$, that is : $\tilde{p}_1 = \frac{c}{3}(5L-7a)$. On the other hand, the solution p_1' - say - to problem (2) is easily derived as

$$p_1' = \frac{c}{6}(5L-4a)\ .$$

Since the inequality $a < \frac{L}{2}$ implies that $p_1' < \tilde{p}_1$, the concavity of $R_1(p_1,p_2^*)$ in the domain D_{11} ensures that $R_1(p_1,p_2^*) \leqslant R_1(p_2^* + c(L-2a)\ ,p_2^*)$ for all $p_1 \in D_{11}$. On the other hand, an easy calculation shows that $p_1 = \frac{c}{3}(L+a)$ is solution to problem (1) for $a < \frac{L}{2}$, which completes the proof of Lemma 1.

□

LEMMA 2 :

Let $p_1^* = \frac{c(L+a)}{3}$ *, and assume* $a = b = F < \frac{L}{2}$ *. Then either,*

$$\forall\ p_2\ ,\quad R_2\left(p_1^*\ ,\ \frac{c(2L-a)}{3}\right) \geqslant R_2(p_1^*,p_2)\ ,$$

or

$$\forall\ p_2\ ,\quad R_2(p_1^*,p_1^*) \geqslant R_2(p_1^*,p_2)\ .$$

Proof : In any case, if a price $\tilde{p}_2$ verifies the property :

$$\forall\ p_2\ ,\quad R_2(p_1^*,\tilde{p}_2) \geqslant R_2(p_1^*,p_2)\ ,$$

it must be that $\tilde{p}_2$, after substitution for b and F , is solution of either

$$\underset{p_2 \in D_{23}}{\mathrm{Max}} \left(L - \frac{p_2 - p_1^* + c(L-a)}{c}\right) \cdot p_2 \tag{1}$$

or

$$\underset{p_2 \in D_{21}}{\mathrm{Max}} \left(L - \frac{p_2 - p_1^* + ac}{c}\right) \cdot p_2\ , \tag{2}$$

or

$$\underset{p_2 \in D_{22}}{\mathrm{Max}}\ (L-a) \cdot p_2\ , \tag{3}$$

when D_{21} , D_{22} and D_{23} are defined as in Proposition 1. Let us show that, if $a < \frac{L}{2}$, the solution $\tilde{p}_2$ to problem (3) must lead to a revenue $R_2(p_1^*,\tilde{p}_2)$ which exceeds $R_2(p_1^*,p_2)$ for all $p_2 \in D_{23}$, leaving us with either case (2), or case (3). First, it is clear that $\tilde{p}_2$ solution of problem (3) is equal to $p_1^* + c(F-a) = p_1^*$ (where the last equality follows from $F = a$), so that we have necessarily that

$$R_2(p_1^*,p_1^*) \geqslant R_2(p_1^*\ ,\ p_1^* - c(L-2a))\ .$$

It is therefore sufficient to show that $R_2(p_1^*\ ,\ p_1^* - c(L-2a)) \geqslant R_2(p_1^*,p_2)$ for all $p_2 \in D_{23}$. Since $R_2(p_1^*,p_2)$ is concave in the domain D_{23} , the last inequality must hold if the unconstrained solution $\tilde{p}_2$ to problem (1) exceeds $p_1^* - c(L-2a)$. An easy calculation shows that $\tilde{p}_2 = \frac{c(L+4a)}{6}$, which exceeds $p_1^* - c(L-2a)$ if $a < \frac{L}{2}$. On the other hand, it is easy to verify that $p_2^* = \frac{c}{3}\ (2L-a)$ is solution to problem (3) when $a < \frac{L}{2}$, which completes the proof of Lemma 2.

□

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